# Collective Protection Using Non-Thermal Plasma and Carbon Filtration

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# Outline

- Concept Introduction/Motivation
  - Non-Thermal Plasma (NTP)
  - NTP-Carbon Hybrid
- Modular System for CBRN Protection
  - NTP reactor design – power delivery
  - Breathable air stages – design and selection
    - Assess NOx & ozone production from NTP
    - Activated carbon polishing
- Live Agent Work

# System Requirements

- Confined Space Application
- Requirements:
  - Portable
  - Specified flow of at least 10 CFM
- Limited power availability
- Simplistic in start-up and operation
- Minimal maintenance and logistics
- Simplistic operation-to-operation maintenance

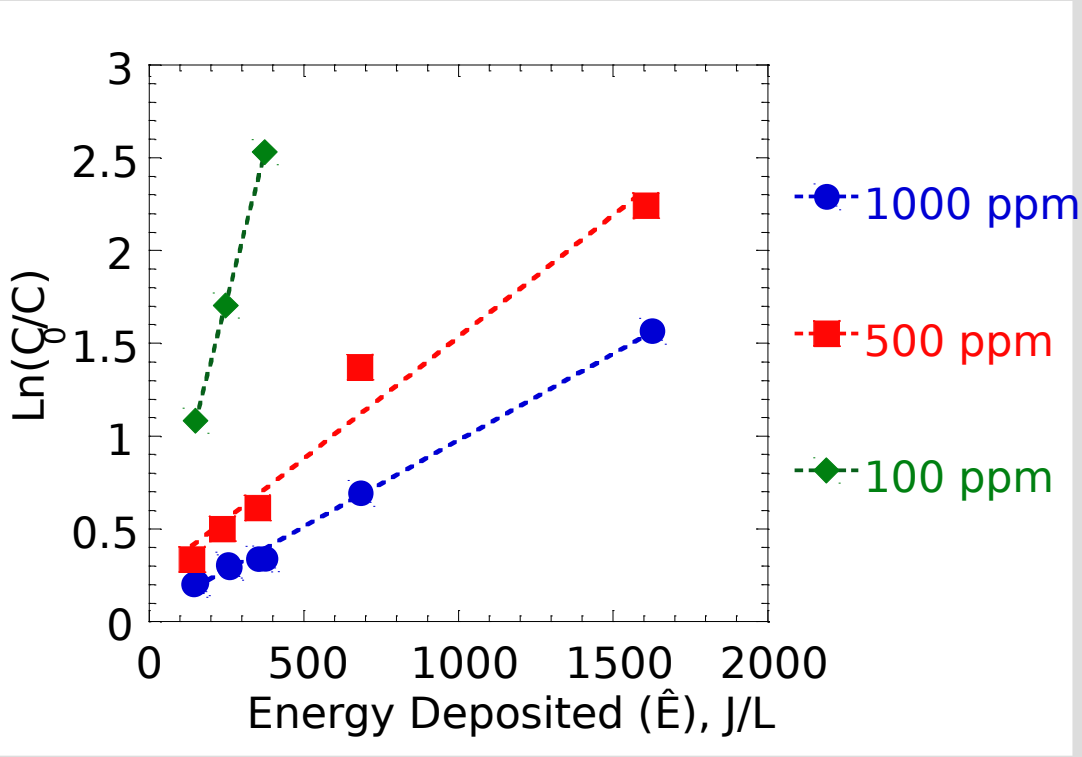
# Non-Thermal Plasma: Discharge Initiation

# Non-Thermal Plasma: Dielectric Barrier Discharge

- Only electrons are ‘hot’.
- Gas can be passed through discharge resulting in treatment.
- Gas remains relatively cool, hence the common term of ‘cold plasma’. Similar to a neon sign.
- Active species for oxidation include $N_2^+$, $O_2^+$, N•, O•, •OH, •$O_2$H, and $O_3$.

# NTP Typical Data Set

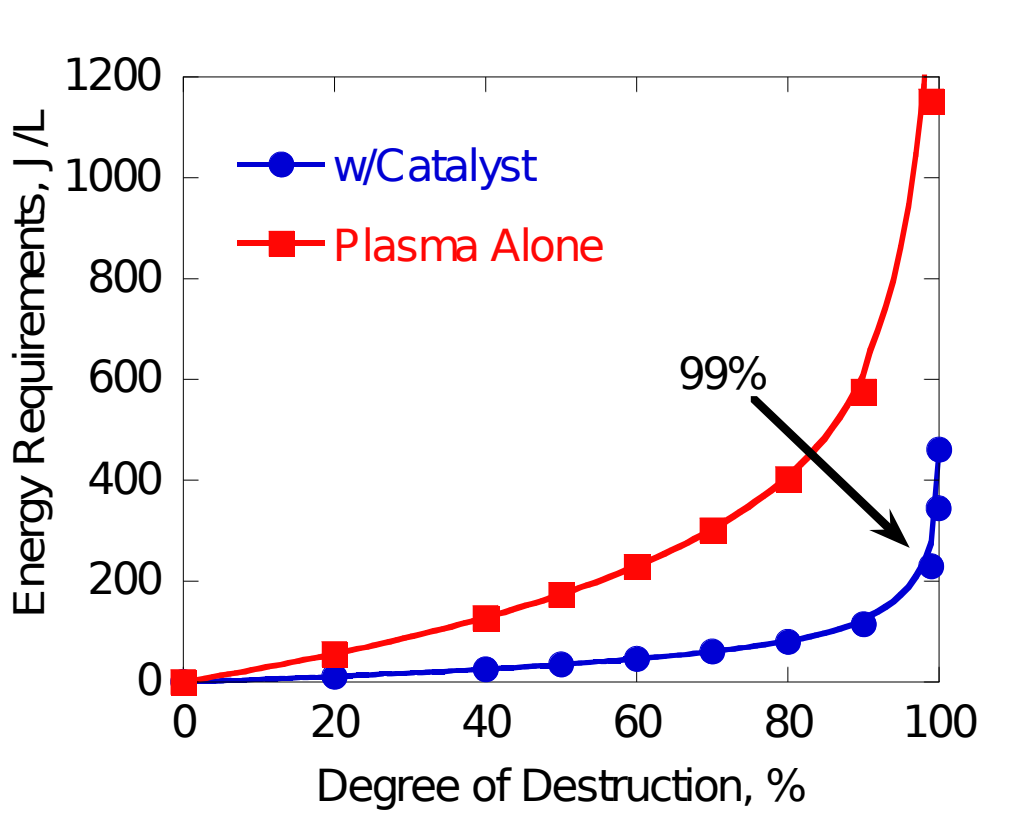
## Chlorobenzene in Air




- Inert packing – glass
- $Ln(C_0/C) = \hat{E}/\beta$
- $\hat{E}=P/Q \rightarrow J/L$
- More energy required as concentration ↑

# Motivation for Hybrid System

- 500 ppm Acetonitrile in Air with Pt/Pd catalyst in NTP at room temp.
- Drawback of NTP is that very high degree of organic destruction is prohibitive due to high energy cost.
- Energy cost for 80-90% contaminant destruction is manageable.
- Solution is to integrate plasma with sorbent.

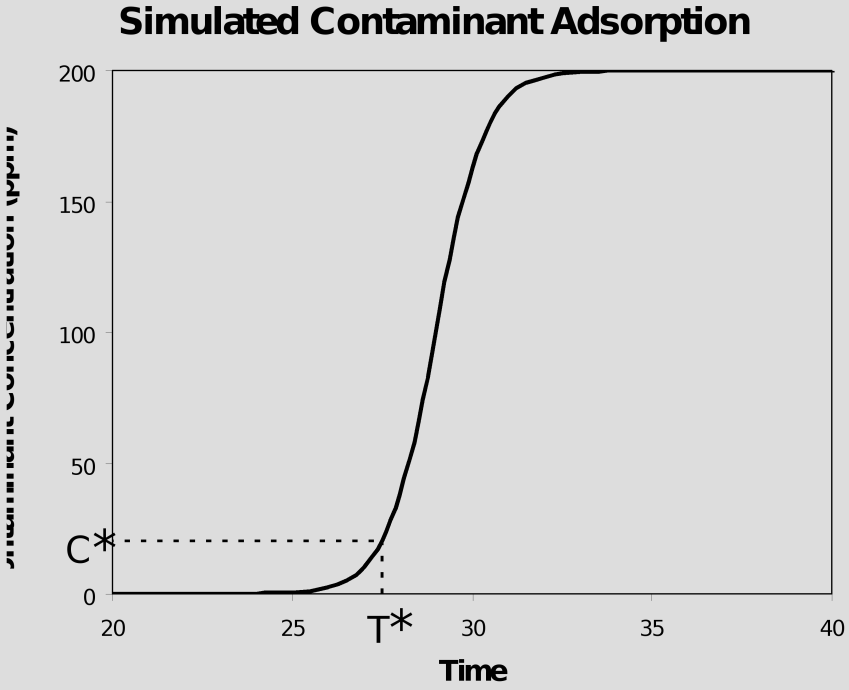


# Carbon Breakthrough

Simple Breakthrough Model: Wheeler

$$t_b = \frac{w_e}{C_0 Q}\left(w - \frac{\rho_B Q}{\kappa_v}\ln\left(\frac{C_0 - C}{C}\right)\right)$$

$C_0$ decrease = $t_b$ increase




C* - NIOSH safe contaminant level
T* - Carbon life (breakthrough time)

Contaminant destruction via NTP extends carbon life (T*), providing extended active protection and minimizing size.

# CBRN Protection Employing NTP

- Aggressive and non-selective oxidation: C & B
- Charge delivered to particulates for effective collection:  B & R/N
- Operation at low temperature
  - Advantage over other oxidation technologies
- Minimal maintenance and reduced logistics
  - Advantage over sorption alone

# Breathable Air

- Long time challenge for NTP is the production of noxious gases during gas treatment.
- Assess products of NTP processing

  Acid gases: HCl, $H_3PO_4$, $SO_x$, HF, etc.

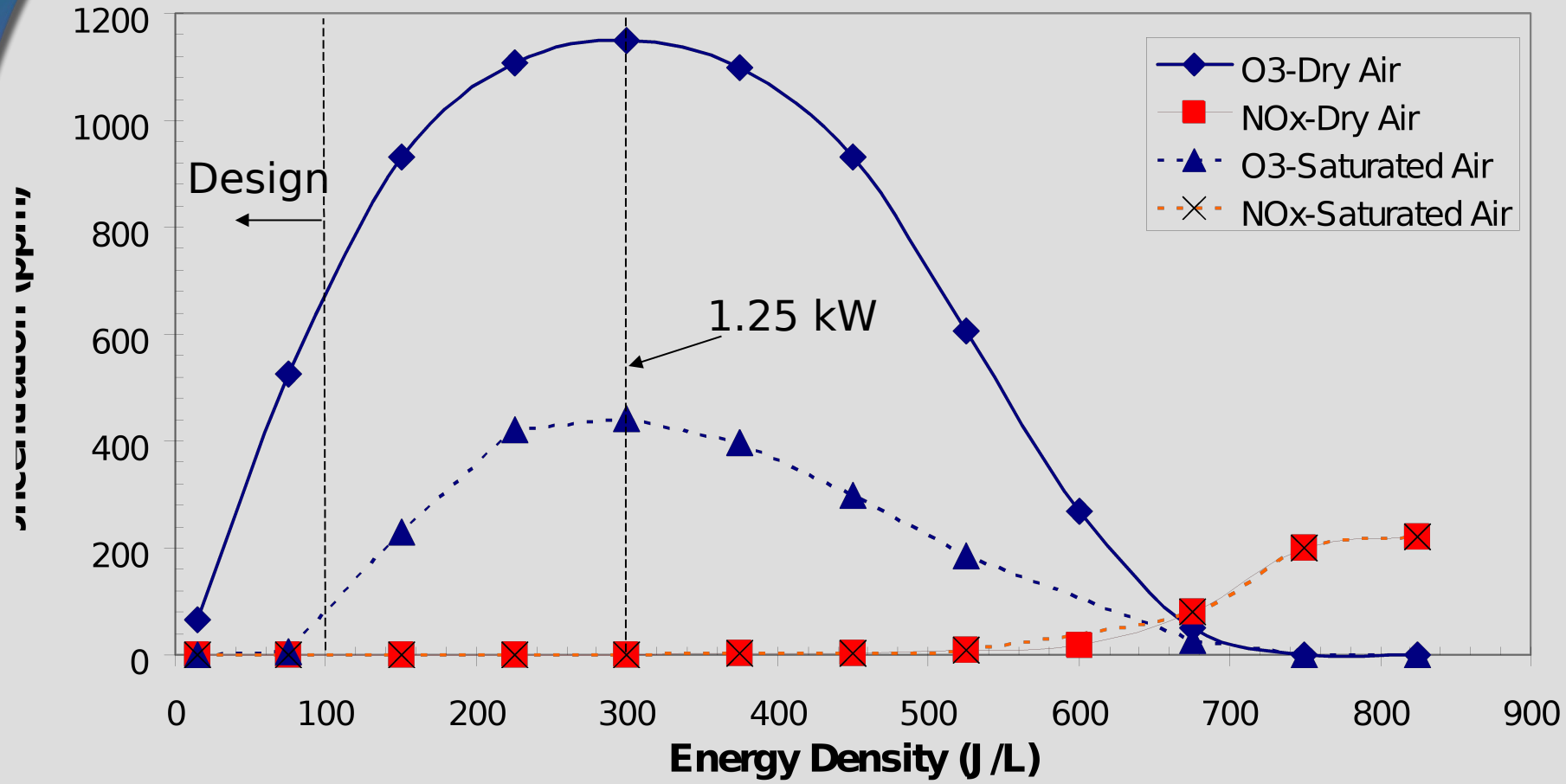
  NOx: NO, $NO_2$

  Ozone: $O_3$

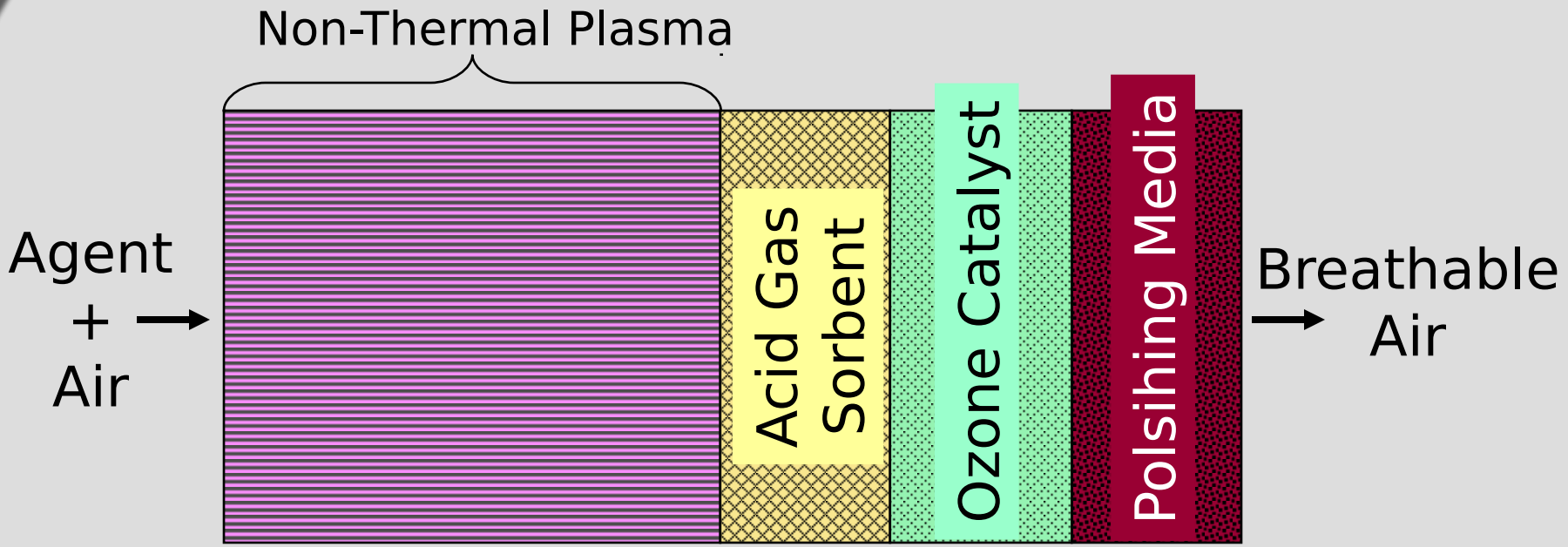
- Evaluate ozone degradation catalyst and acid gas getter materials
- Size breathable air filtration stages
- Determine suitable polishing medium

  Trade-off of plasma and catalyst stage size

# Non-Thermal Plasma Reactor Products for Varying Humidity



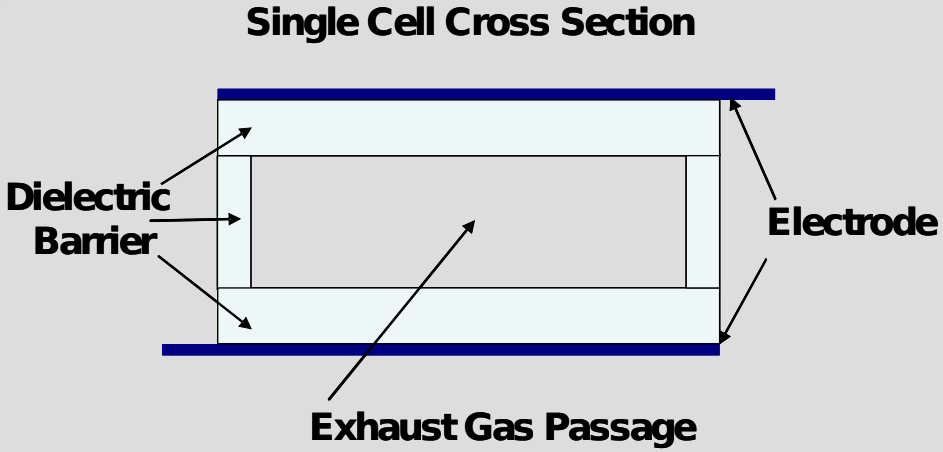
# Modular System for CB Protection




- Plasma results in aggressive non-selective oxidation.
- PM trapped and destroyed. Organics are oxidized.
- Plasma targets >90% destruction of chemical species.
- Polishing stage used to obtain breathable limits

# Plasma Reactor Design: Extremely Compact Forms Possible

Sized for a 2.0 liter engine



- Development of plasma technology initially focused on diesel exhaust treatment and VOC oxidation alternative to TCO.
- Automotive platforms altered for CBRN protection applications.

**Reactor Can**

- **Weight: 2.9kg**
- **Length: 82mm**
- **Width: 160mm**
- **Height: 90mm**

**Reactor Brick**

- **Length: 40mm**
- **Width: 115mm**
- **Height: 46mm**
- **Active Area: 15.4cc**

# Power Delivery Options

- Power delivery is flexible.
- 110 or 220 transformers are readily available so worldwide operation from wall power relatively easy.
- 12, 18, 24 V also possible through existing power supplies at power levels lower than 1500 W.
- Inverters could be used for higher power requirements.

# Acid Gas Sorbent

- Unisorb Mark 2
- Adsorbent sizing basis
  - Kinetically Limited
    - 10,000 ppm slug to 100 ppm
  - Capacity Limited
    - 100 ppm constant over 8 hours at 250 L/min air flow rate

# Ozone Removal Catalyst

- Carulite 200 Catalyst
- Production of $O_3$ from Plasma
  - 300 Watts
  - 50% rh
  - 525 ppm $O_3$
- Linear Velocity
  - Zero order kinetics → 2.2 ft/sec max to obtain desired contact time

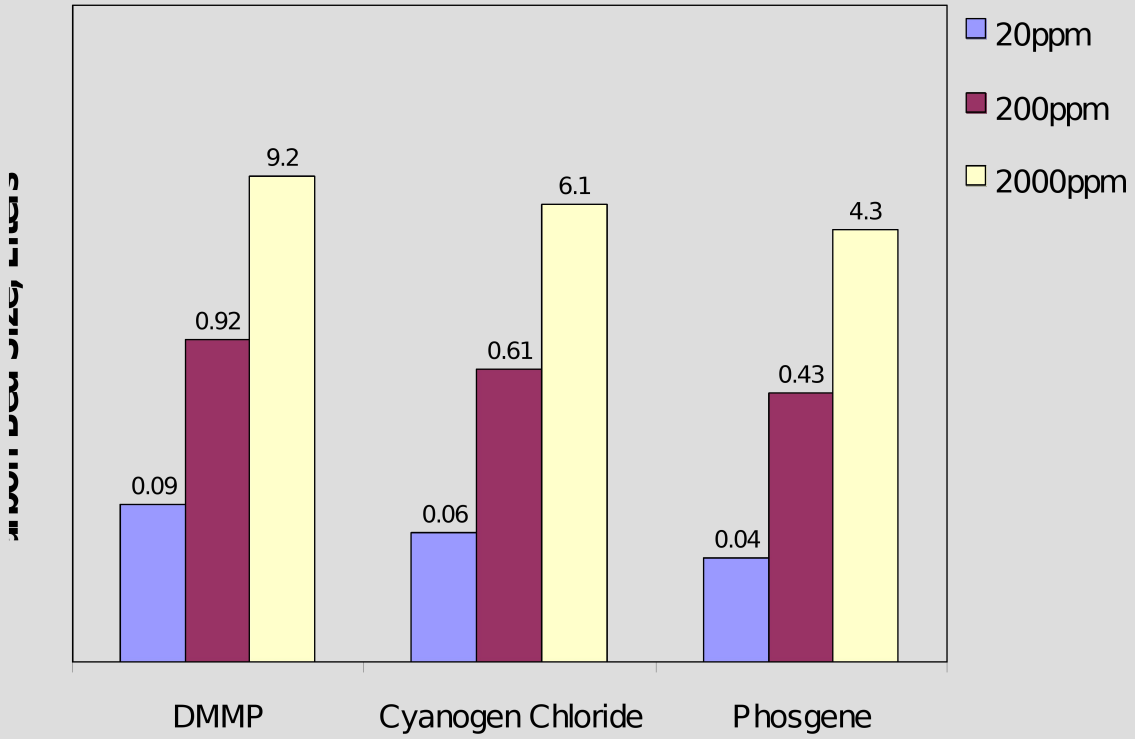
# 3M™ FR-64 Carbon

Originally designed for full facepiece military-style respirators for Emergency Response.

Has been tested (to military specs) to filter wide range of chemical warfare agents: nerve agents, tear agents, blood agents, chlorine, phosgene, chloropicrin, diphenylchloroarsine.

Manufactured in accordance with U.S. MIL-C51560(EA) and EA-C-1704.

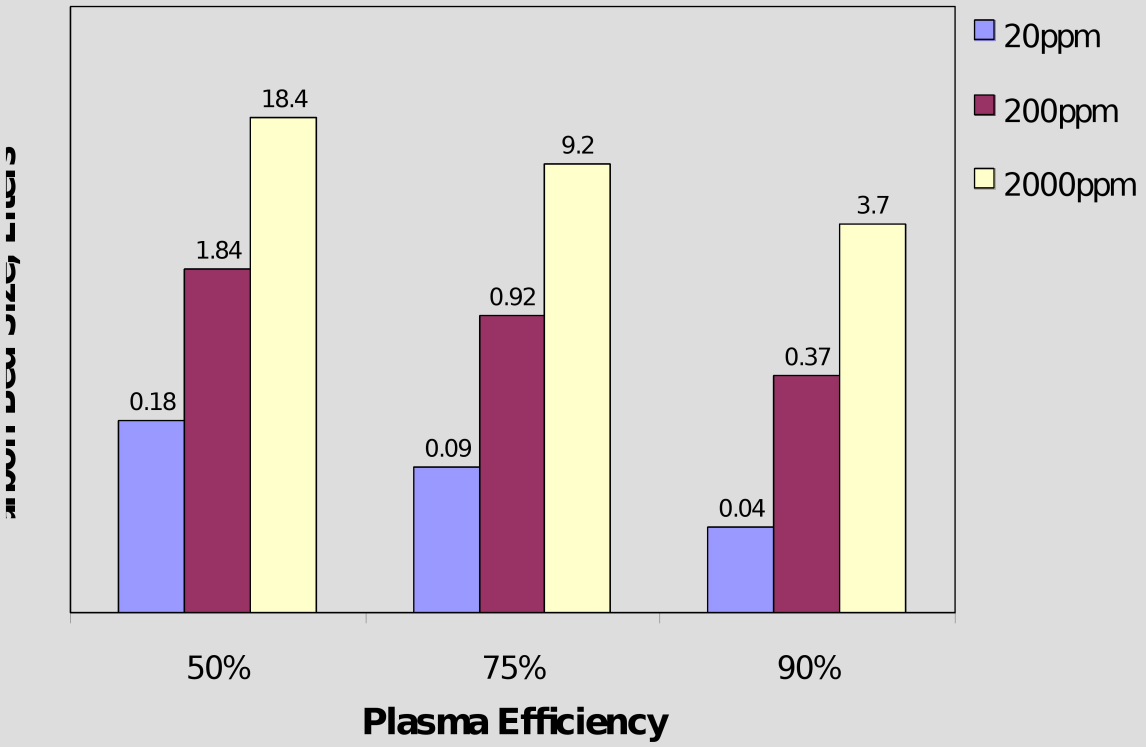
# Concentration Effect on Carbon Bed Size




8 hour exposure time, 250 L/min air flow

75% Plasma efficiency

# Combined Plasma Efficiency and Concentration Effect on Carbon Bed Size




8 hour exposure time, 250 L/min air flow

Simulation agent: DMMP

# Live Agent Exposure Predictions

- For non-persistent agents (chlorine, phosgene, sarin), proximity of source is the critical factor
  - Near point of release results in high levels
  - At distances approaching 1 mile there is little to no exposure even if wind is in an unfavorable direction
- For persistent agents (VX, mustards), exposure time is critical.

# Agent Impact Factors

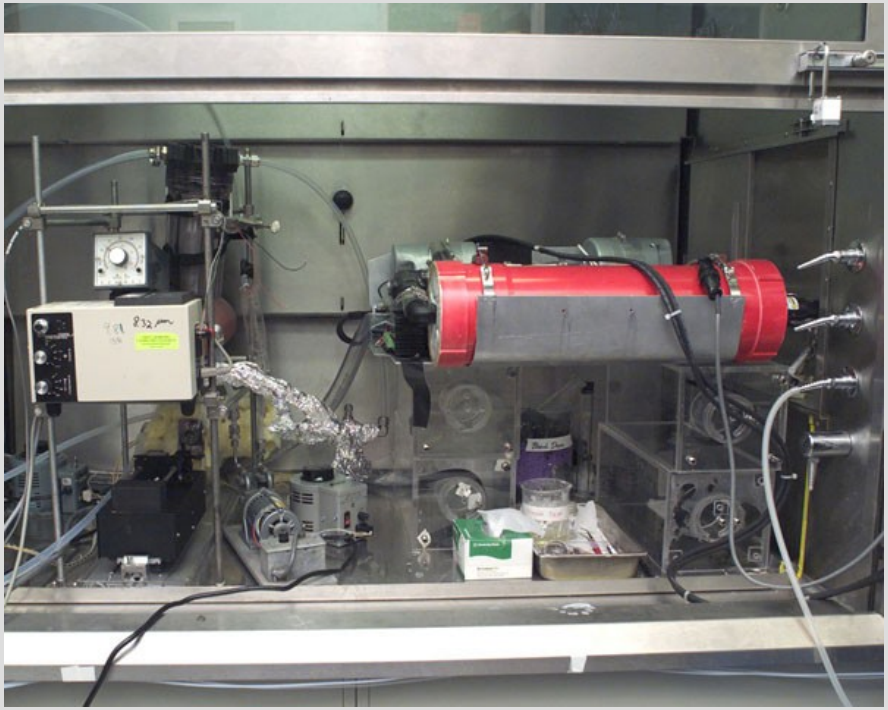
| | VP (mmHg) | BF Levels (ppm) | ID50 (ppm•min) | LD50 (ppm•min) |
|---|---|---|---|---|
| Chlorine | Gas | 30-100K | 720 | 7600 |
| Phosgene | 1.2 | 1600 | 640 | 1280 |
| HCN | Gas | 30-100K | Variable | 1800 |
| Cyan. Chl. | Gas | 30-100K | 2800 | 4400 |
| GB-Sarin | 2.9 | 3800 | 30 | 40 |
| VX | 0.0007 | 0.9 | 20 | 40 |
| S-Mustard | 0.07 | 92 | 800[1] | 600[2] |
| N-Mustard | 0.3 | 400 | 4400[1] | 600[2] |

[1] Contact exposure
[2] Inhalation exposure

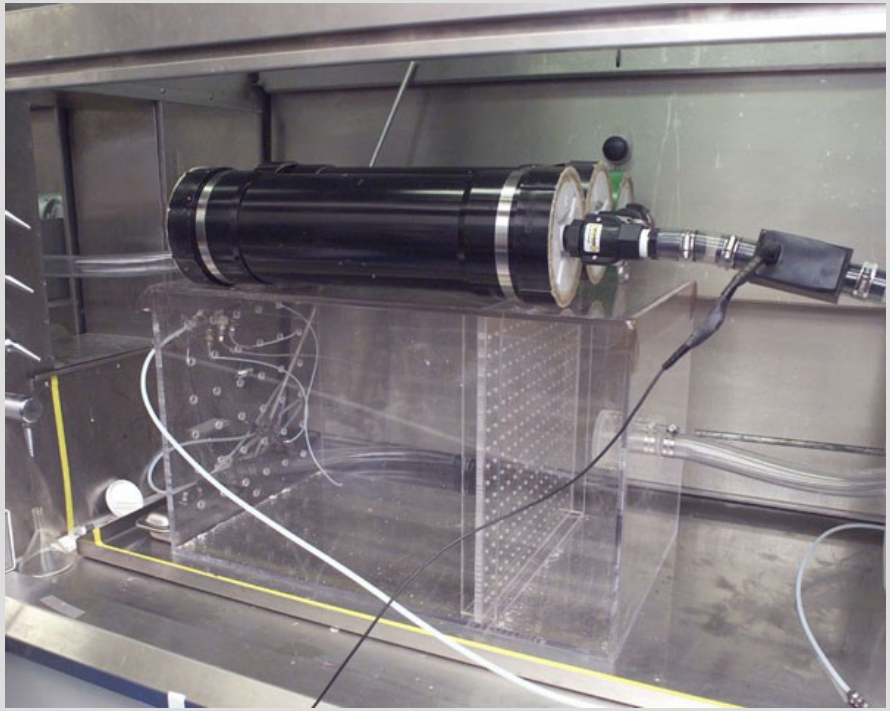
# Live Agent Work Completed at Dugway Proving Ground

- System tested with HD and GB. Performance within specifications.

Disseminator, Plasma, and Acid Gas



Ozone and Carbon Stages



# Future Work

- Should be possible to integrate breathable air stages. This will allow even smaller profile.
- First prototype focused on chemical hazards. Still needs to be tested against BRN. Likely design changes based on results (*eg*., pulsed power needed for PM collection).
- Need to understand thermal and E-M signature better and potentially shield device.
- Begin looking at other applications such as protection of tented structures, buildings, safe havens, and other vehicles.

# Conclusion

- Plasma-carbon hybrid CP designed and demonstrated.  Advantage is smaller/lighter system or longer operational life.
- Should be possible to reduce size through integration of stages.
- Benefit of approach goes up with air flow requirement.  Plasma reactor and power supply size/weight become much less than carbon volume avoided as flow increases.
- Likely not suitable for individual protection.
- Vehicles, aircraft, tents, and buildings are potentially suitable uses of the technology.